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Preliminary Evaluation of Greases for Space Mechanisms Using a Vacuum Spiral Orbit Tribometer

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Abstract

Most currently used greases for space applications are based on perfluoropolyalkylethers (PFPE) and multiply alkylated cyclopentane (MAC) oils. Evaluation of the greases includes outgassing properties, rheological behavior, and particularly the ability to create EHL films under conditions as close as possible to an actual application. A spiral orbit tribometer (SOT) has been developed to conduct accelerated tests under realistic conditions. The SOT was employed to evaluate two greases used in space mechanisms: a PFPE oil with polytetrafluoroethylene (PTFE) thickener, and a multiply alkylated cyclopentane (MAC) oil with n-octadecylterephthalamate soap. The results from the greases are in agreement with results previously obtained with the base oils.

I-Introduction

Accelerated tests are used to evaluate the behavior and the lifetime of several space materials, particularly fluid lubricants. The reliability of spacecraft mechanisms mainly depends upon the lubricants' ability to last for the increasing mission lifetimes. The Spiral Orbit Tribometer, fully described in a previous paper [1], provides the opportunity to vary many parameters in a controlled way and to monitor data such as the lubricated lifetime, friction coefficient, contact resistance and degradation products. The objective of this work was to evaluate two different greases used for space applications: a PFPE oil with PTFE thickener, and a multiply alkylated cyclopentane oil with n-octadecylterephthalamate soap.

II-Experimental

A Spiral Orbit Tribometer (SOT), shown in Figure 1 simulating an angular contact bearing was used. A 12.7 mm (1/2 inch) ball rolled between a fixed plate and a rotary one. The load, providing a mean Hertz stress of 1.5 GPa, was applied to the fixed plate with a spring. The ball was returned to its initial track by a guide plate, inducing a sliding motion between the ball and the plates. The friction coefficient was determined from the force the ball exerted on the guide plate when it returned to its original orbit. A

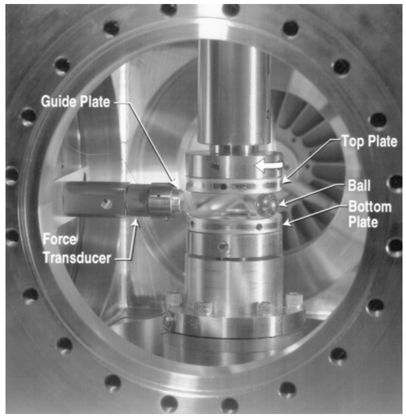


Figure 1: Spiral Orbit Tribometer operating under vacuum.

maximum current of 1 mA was sent through the disks and the ball, and the resistance of the ball-plate contacts was determined by the voltage drop between the two plates.

Tests were conducted at room temperature (≈ 23 °C), under ultrahigh vacuum (1.3×10^{-6} Pa) with 440C specimens. The surfaces of the ball, disks and guide plate were polished (Ra≈0.05 µm) with an alumina slurry. Specimens were rubbed with a levigated alumina slurry and rinsed with tap water. Then, they were ultrasonically cleaned with hexane and deionized water for 10 min each. Next, they were dried with dry and filtered nitrogen. Finally, they were treated for 15 min under UV/ozone. The cleaning procedure is fully described in reference [2].

III-Materials

Balls were then lubricated with a very small amount of lubricant (10–90 µg). The weight gain was determined using a high precision balance. The grease was applied by rolling the ball several times between two elastic membranes. The fluorinated grease is manufactured with a linear PFPE oil and PTFE thickener. The second grease contained a MAC oil with an n-octadecylterephthalamate soap and additives (a phosphate, an amine and a hindered phenol). An infrared analysis (spectrometer FTIR Nicolet 760) was conducted to confirm that both oil and thickener were applied on the surface of the ball. A mass spectrometer (Dycor Quadrupole Gas Analyzer) was attached to the vacuum chamber to analyze the decomposition products of the fluorinated lubricant during the test.

The composition of the lubricants is given in Table 1, with the ones of base oils.

Lubricant type		**Composition**	
neat oil	***grease***	***additives***	***thickener***
PFPE		none	*N/A*
	PFPE-grease	none	PTFE
MAC		anti-wear, anti-oxidants	*N/A*
	MAC-grease	anti-wear, anti-oxidants	n-octadecylterephthalamate soap

Table 1: Lubricants composition

The continuous consumption of lubricant during the test eventually caused an increase of the friction coefficient when the lubricant was consumed. The friction coefficient was used as failure criteria when it exceeded 0.28. Data acquisition was done based on a Labview® control program. The test started automatically when the pressure was below 1.3×10^{-6} Pa, and shut down when the failure criteria was reached. Four tests were conducted for each lubricant at a speed of 210 rpm. Normalized lifetime was determined by calculating the number of orbits to failure per microgram of lubricant employed.

IV-Results

Results are shown in Figure 2. To make the comparison easier, results obtained with the base oils (PFPE and MAC) are included. The lifetimes with the multiply alkylated cyclopentane based lubricants are longer than the lifetimes obtained with the fluorinated lubricants under the same test conditions. This behavior is in agreement with previous tests conducted with the same base oils in a ball-bearing test rig [3]. The MAC lubricant has shown at least a seven times life improvement over the PFPE. Several of the MAC bearing tests are still operating.

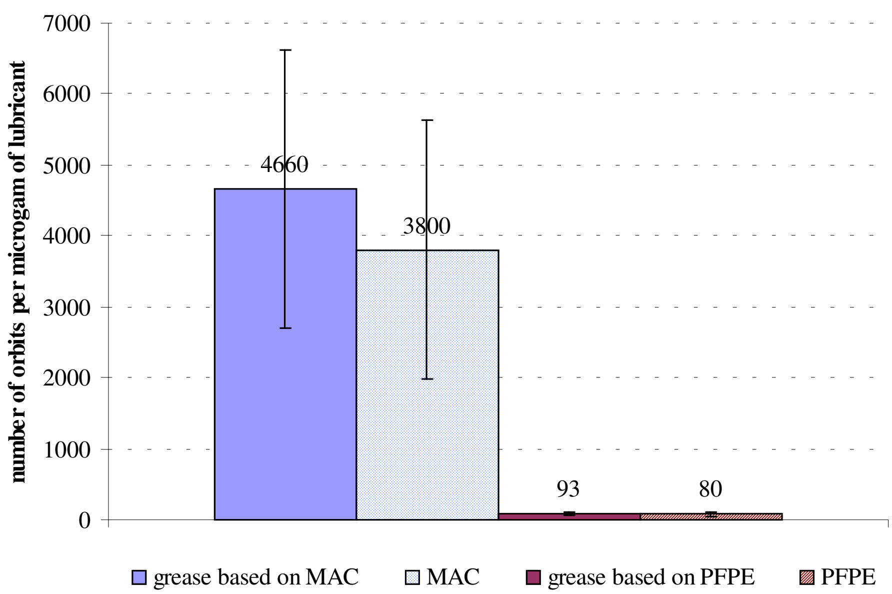
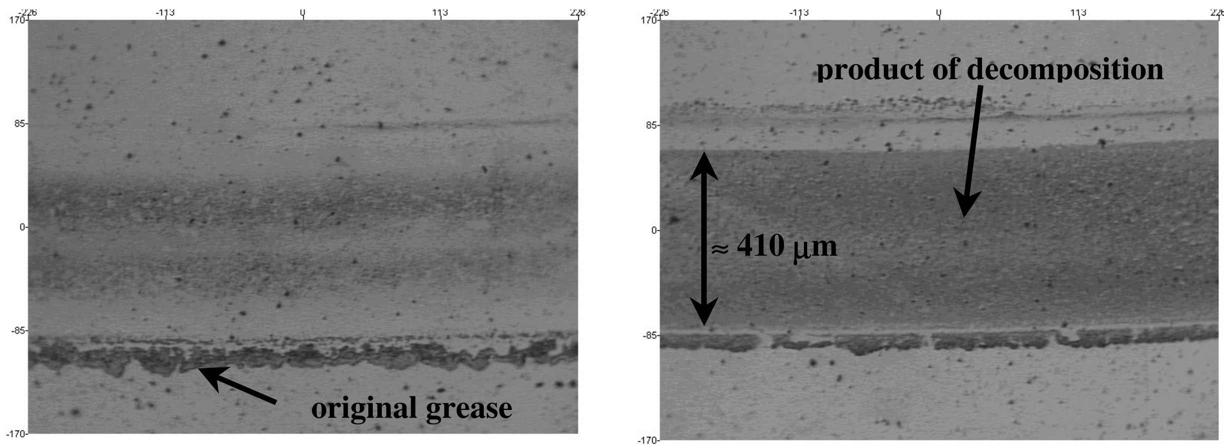


Figure 2: Relative lifetimes of the different greases tested with the SOT.

Micrographs of the rolling tracks on the disks were taken for both lubricants and are shown in Figure 3. The pictures are typical of the ones obtained on the races of a grease-lubricated ball bearing. In both cases, the tracks are covered with a "brown" material, the result of the degradation of the greases. An infrared analysis in the center of the track did not reveal any traces of lubricant. The infrared signatures on the edges were those of the original greases that were used. This confirms that both oil and thickeners were present despite the small amount of lubricant used. In the case of the PFPE based grease, the infrared spectra revealed some carbonyl compounds. This kind of product is



a b

Figure 3: Pictures of tracks for the two greases evaluated
a: grease based on PFPE, b: grease based on MAC.

typical of the degradation of fluorinated lubricants [4] and is consistent with the fluorocarbon fragments observed in the mass spectrometer.

Another interesting result is the shape of the friction coefficient as a function of ball orbits number. The PFPE grease has shown a sudden increase after a steady value, while the MAC had a more progressive failure (Figure 4). The PFPE based grease also has also yielded a higher friction coefficient (0.12) compared to the MAC based grease (0.08). The corresponding resistance profiles were the same with both lubricants: a sharp increase, followed by a decrease and then a plateau until failure.

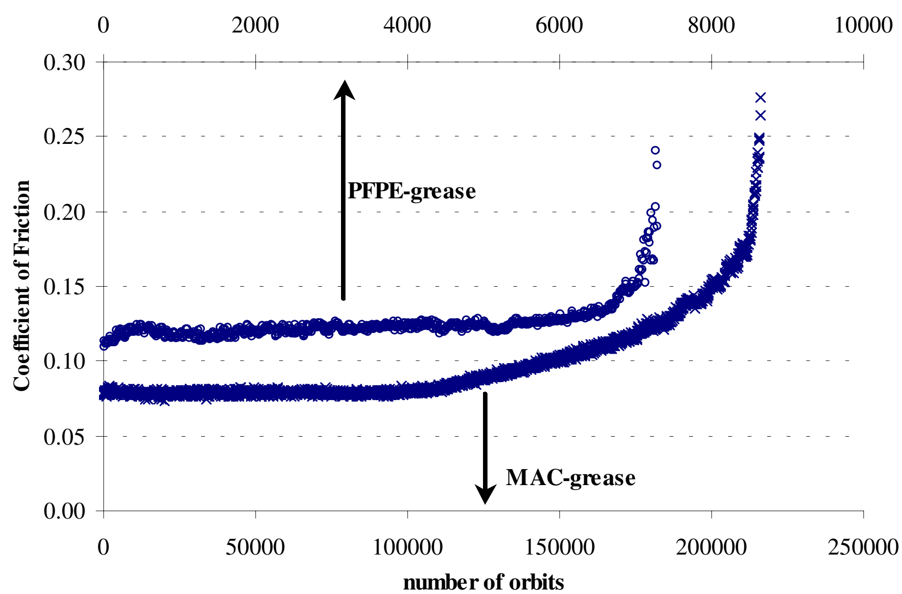


Figure 4: Comparison of friction coefficient profile of the two greases.

V-Discussion

In the case of the MAC based grease, a link between the friction coefficient evolution and the resistance profile can be established. The end of the constant value of the friction coefficient corresponds to the end of the decrease in the resistance. An example is shown in Figure 5. The first increase observed in the resistance profile corresponds to the film formation of lubricant (oil and thickener) between the ball and the disks. Since the tests were conducted with very small quantities of lubricant, this film was quickly removed. Progressively, the resistance of the contact decreased, due to the removal of the thickener film on the stainless steel surfaces. Since the load was constant during the test, the resistance changes were only caused by the modification of the film thickness and/or the lubricant nature. Then, the resistance remained constant until failure. This could be the result of direct contact between the ball and the disks through the oil and thickener films. It could correspond to a boundary lubrication regime, and it is consistent with the progressive increase of the friction coefficient.

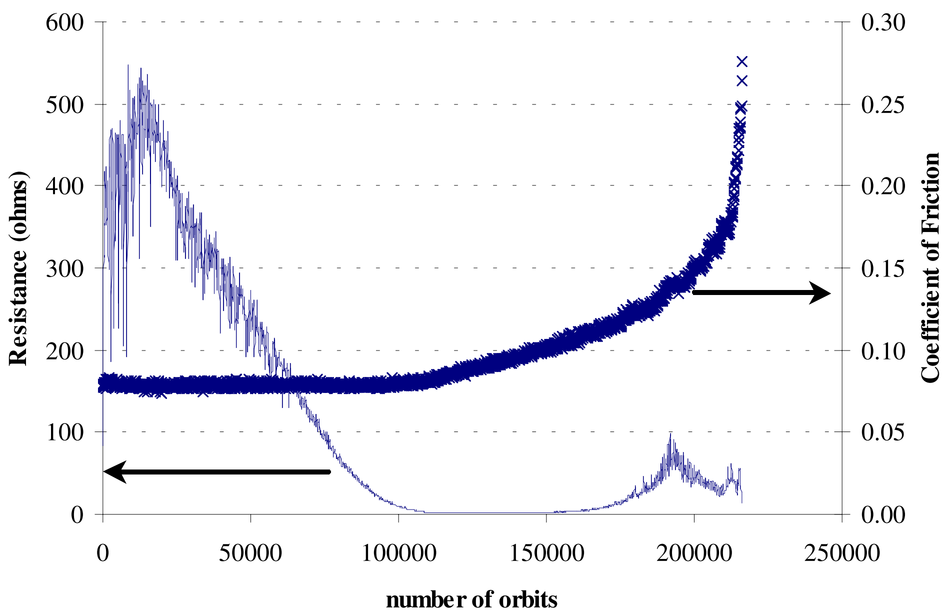


Figure 5: Correspondence between coefficient of friction and resistance profile in the case of the multiply alkylated cyclopentane with n-octadecylterephthalamate soap grease.

This analysis can be applied to the fluorinated grease, although the phenomena occurred in only a few thousand orbits. In this case, the tribochemical degradation of this kind of lubricant must be considered, and has already been observed in many cases [5, 6]. A mass spectrometer was attached to the SOT while the PFPE based grease was tested. The conventional mass peaks at 66 and 69, evidence of PFPE degradation, were observed immediately after the test started. If the increase and decrease of resistance were also observed in the first thousand orbits, the tests did not last long once the resistance has reached its constant value, although the friction coefficient remained constant. According to the previously described mechanism, resistance should correspond to the disappearance of the protective layer made by the thickener. But in this case, much of the fluorinated oil was already consumed due to the test conditions (high load). The rapid degradation process did not allow a long lifetime and is responsible for the sudden failure with the fluorinated grease.

VI-Summary of Results

The grease based on the multiply alkylated cyclopentane oil, the n-octadecylterephthalamate soap and additives has a significantly longer lifetime than the fluorinated grease. This result is an agreement with ones previously obtained with the base oils [3].

The plot of coefficient of friction versus ball orbit number (Figure 4) shows that the failure of the PFPE grease is quite abrupt compared to the more gradual onset to failure exhibited by the MAC grease. The gradual behavior allows failure to be anticipated well before it actually occurs. The more abrupt behavior of the PFPE grease does not permit such advance notice of failure. The MAC grease has shown a progressive increase of the friction coefficient until the failure, and in close correlation with the resistance of the contact.

A possible quantification of the degradation rate of the fluorinated oils and greases will soon be conducted. It will be based on tests with the Spiral Orbit Tribometer and mass spectrometer analysis.

VII-Conclusion

These experiments are consistent with previous ones with the same or equivalent liquid lubricants. Moreover, they confirm the ability of the Spiral Orbit Tribometer to run accelerated tests to evaluate different tribological parameters.

The Spiral Orbit Tribometer (an angular contact bearing simulator) can be used to evaluate the performance of greases.

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